An Optical Parametric Amplifier for Profiling Gases of Atmospheric Interest

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1. ABSTRACT

This paper describes the development of a lidar transmitter using an optical parametric amplifier. It is designed for profiling gases of atmospheric interest at high spatial and temporal precision in the near-IR. Discussions on desirable characteristics for such a transmitter with specific reference to the case of CO_2 are made.

2. INTRODUCTION

Differential absorption lidar (DIAL) is a powerful technique that can be used to profile gases of atmospheric interest with high spatial and temporal resolution. Although there exist a number of techniques for generating light at UV and visible wavelengths tunable, high average power radiation in the near and mid-IR has been more difficult to develop especially in a package suitable for autonomous operation in the field. A study of frequency conversion techniques suggested that optical parametric amplifiers (OPAs) could facilitate the development of a device for converting high power pump radiation into tunable IR with high efficiency. For making range resolved measurements desirable characteristics for such an OPA are high conversion efficiency, short pulse widths (to permit resolving features over short distances – greater than ~10 meters), single longitudinal mode operation, transform limited pulses, operation within an 'eye safe' region of the spectrum and extremely low frequency jitter.

The investigation into high power near-IR light sources has been driven by the measurement requirements of the North American Carbon Program [1] to make range resolved CO_2 measurements within the planetary boundary layer (PBL – typically below 3 kilometers during the day and less than several hundred meters at night) to a precision of ~1 ppmv (parts per million volume) at a resolution of between 10-250 meters. The CO_2 mixing ratio in the lower atmosphere is ~370 ppmv. This high precision is required to identify spatial and temporal variations in CO_2 fluxes that can then be used to identify terrestrial sources and sinks for CO_2 to within tens of kilometers.

Recent advances in both detector technology and fiber lasers, originating within the telecommunications sector, have provided the tools required to measure total column CO_2 within the 1.5-1.6 micron spectral region. Leveraging these efforts and building upon current NASA research demonstrated that a profiling lidar could be developed that would be able to utilize direct, as opposed to coherent, detection thereby minimizing cost and facilitating the development of a instrument suitable for deployment to remote locations.

Fiber lasers have demonstrated CW output powers >10 watts with good spatial and temporal characteristics. Unfortunately while fiber lasers offer a very attractive solution to making atmospheric column measurements they experience a low duty cycle when operated at the high repetition rates required for profiling. Going to shorter pulses for enhanced spatial resolution makes the situation more difficult by lowering the duty cycle even more. High averaged power however is crucial to any measurement strategy attempting to profile CO_2 in the near-IR because of the relatively weak signal returns that arise when not using hard targets for signal generation.

3. INSTRUMENT

OPAs were investigated as an alternative to fiber lasers because of their ability to generate high average power at high pulse repetition rates. OPAs possess a number of very attractive features as a source of pulsed IR radiation among them a very short pulse width and easy tunability (Fig. 1). They can utilize a commercial Nd:YAG oscillator/amplifier for the pump that can produce very short nanosecond pulses tailored to the measurement of interest. Output pulses are single longitudinal mode and transform limited. The use of commercial off the shelf technology facilitates the goal of developing a breadboard instrument that can serve as the proto type for a rugged, low cost, field deployable instrument. A distributed feedback diode laser (DFB) seeds the OPA at the desired wavelength. It can be locked to the wavelength of interest using either a gas

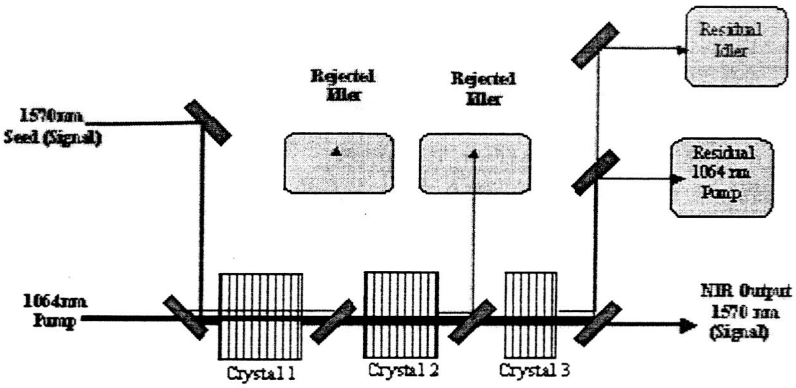

Fig. 1. An Optical Parametric Amplifier for High Power Operation in the IR

cell or a wavemeter/drive current feedback loop. Using the wavemeter/current feedback technique we have demonstrated long term locking (>25 hours) to better than 0.2 pm. Because of its high conversion efficiency periodically poled lithium niobate (PPLN) is used to convert the 1064 nm pump radiation into signal and idler. The idler, at 3.3 microns, is not used. A modification to the conventional technique is employed to maximize pump conversion into the signal without experiencing back conversion into the pump by separating the parametric conversion process into three separate steps and discarding the idler after each one. The calculated conversion efficiency is >30% from the 1064 nm pump into the signal at 1570 nm.

A practical device suitable for profiling CO_2 within the PBL must restrict the time averaged frequency jitter to less than ~130 MHz – full width at half maximum. This minimizes the uncertainty in the effective CO_2 absorption cross-section to less than 1 part in a 1000 (at sea level), a necessary condition for a measurement to 1 ppmv. In order to minimize the impact of atmospheric fluctuations upon the measurement the OPA pulse repetition rate should be higher than 1 kHz.

Average powers at 1570 nm will be ~1.5 watts at 10 kHz. DIAL profiling requires two wavelengths, one strongly absorbed by CO_2 and the other not. Both wavelengths will be generated using the same OPA – a 10 kHz repetition rate restricts the maximum altitude to less than ~15 km which is far above the PBL under all conditions.

Signal returns will be produced using both Mie and Rayleigh scattering. Mie scattering, originating with planetary boundary layer aerosols, is capable of generating strong returns within the PBL throughout the year [2].

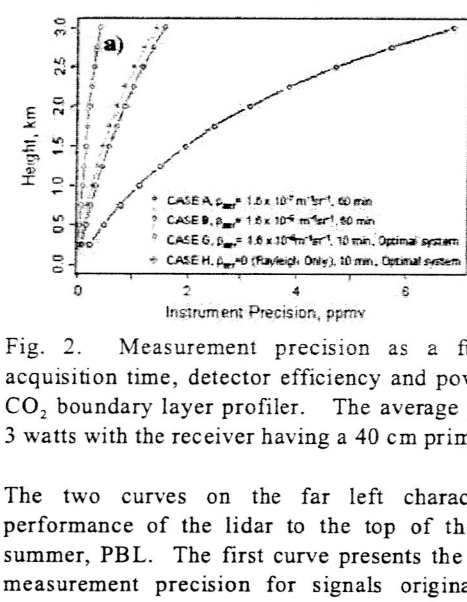

Fig. 2. Measurement precision as a function of acquisition time, detector efficiency and power for the CO_2 boundary layer profiler. The average power was 3 watts with the receiver having a 40 cm primary.

The two curves on the far left characterize the performance of the lidar to the top of the daytime, summer, PBL. The first curve presents the calculated measurement precision for signals originating from both Mie and Rayleigh scattering. The second curve, utilizing only Rayleigh scattering, is included to demonstrate the impact that Rayleigh signals have on the low altitude measurement. Acquisition time was 10 minutes. The strong Rayleigh returns demonstrate that the lidar can retrieve profiles into the free troposphere where aerosol loading is much weaker than the PBL and thereby enable a high precision measurement of CO_2 transport across the PBL-free troposphere boundary.

4. CONCLUSION

The development of an optical parametric amplifier for the profiling of CO_2 within the PBL has been described. This device, when combined with high detection efficiency photon counting InGaAs APDs under development [3], will enable the construction of a small, light weight, DIAL lidar capable of profiling CO_2 at high temporal and spatial resolution.

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